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DRAWINGS ATTACHED

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(54) GENERATOR FOR PRODUCING ULTRASONIC OSCILLATIONS

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a generator for producing ultrasonic oscillations, comprising a resonant circuit and a transducer coupled thereto, a direct current source, the output current of which is converted into an alternating current through two switches controlled by means of a controllable oscillator, and means for applying said alternating current to said resonant circuit whose output energy is transferred to said transducer.

Such ultrasonic generators are used, for example, in cleaning equipment wherein the transducer is connected to a vessel which is partly filled with a suitable liquid and wherein the articles to be cleaned are placed. In its operating condition the generator provides a current of given frequency which is transferred to the transducer i.e. the member converting the electrical oscillations into mechanical oscillations. The frequency is then decisive for the energy which is provided by the transducer and this frequency is normally chosen to be such that this output energy is at a maximum. However, the frequency at which the output energy is at a maximum varies with the quantity of liquid contained in the vessel. In order to maintain the output energy at a maximum the frequency of the oscillator current must therefore be readapted to the mechanical properties of the vessel and its contents prevailing at any instant. This may be effected by manual control of the controllable oscillator every time such is needed. However, in that case it may happen that a variation in the optimum situation is not observed, that the adjustment of the exact frequency value is neglected or that an erroneous adjustment is chosen.

An object of the present invention is to provide a generator of the kind described wherein the required frequency is adapted automatically.

According to the invention, there is provided an ultrasonic generator comprising a direct current source and two switching devices actuated by a controllable oscillator to provide an alternating current, a resonant circuit powered by said alternating current and control means for varying the frequency of said oscillator to optimize the energy transfer of a transducer, in which the control means comprises a resistor in the alternating current circuit, means interposed between the output of said oscillator and said switching devices for modulating the output signal of the oscillator at a lower frequency than the oscillator frequency to produce across said resistor a modulated signal with a signal component at said lower frequency, comparison means coupled to said resistor for deriving an output voltage whose polarity is determined by the phase relationship of said signal component relative to the lower frequency modulating signal and means for applying said output signal as a frequency control signal to said controllable oscillator.

In order that the invention may be readily carried into effect, it will now be described in detail by way of example with reference to the accompanying diagrammatic drawings, in which:

Figure 1 shows a known embodiment of an ultrasonic generator,

Figure 2 shows an embodiment of an ultrasonic generator according to the invention, and

Figure 3 shows the variation of the oscillator current as a function of the frequency of the control signal.

In the known ultrasonic generator shown in Figure 1, a transducer 6 is connected to a vessel 7 containing a liquid. In the operating condition a current is applied to the transducer through the transformer 24. Before this current, which is derived from a direct voltage source 1, is applied to the transformer, it is converted into an alternating current with the aid of switches 20—

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23. The switches 20—23 are operated by a controllable oscillator 13 in a manner such that the current from the direct current source 1 is applied to the transformer alternately by the switches 20, 21 and 22, 23, respectively. The switches 20—23 are formed by power transistors in the embodiment shown.

An oscillator of the type shown in Figure 1 has certain drawbacks. For example, the frequency of the oscillator current will have to be manually readjusted every time in order to maintain the maximum output energy when the level of the liquid in the vessel changes. Furthermore, the transistors require some time to change from the conducting into the non-conducting state so that the two transistor pairs are both conducting during part of each period of the operating current. The resultant periodically occurring short circuit of the output transformer results on the one hand in the current showing peaks and on the other hand it causes switching losses in the transistors which losses cannot be neglected. The occurrence of said peaks entails a limitation of the maximum current which may be interrupted by the transistor. The switching losses entail a limitation of the maximum frequency which may be assumed by the operating current because the period during which the two pairs of transistors are simultaneously conducting increases with frequency.

The above-mentioned drawbacks are obviated in the ultrasonic generator according to the invention. Figure 2 shows a possible embodiment. In this embodiment a direct current from a source 1 is applied through a choke coil 2 to a resonant circuit comprising a capacitor 5 and the primary winding of the transformer 3. The inductance of the choke coil 2 is considerably higher that that of the primary winding of the transformer so that the current is substantially constant. The resonant circuit is tuned to the operating frequency. The current is chopped by switches each comprising the series arrangement of power transistors 10 and 11 and diodes 8 and 9, respectively. The diodes prevent a short-circuit current from flowing during the period when the two transistors are simultaneously conducting. The current flows alternately through the switches 8, 10 and 9, 11. For a suitably chosen Q-value of the tuned circuit the output voltage will be sinusoidal. It is of course alternatively possible to incorporate the secondary winding instead of the primary winding of the transformer in the tuned circuit. The transformer transfers the current to the transducer which converts the electrical oscillations into mechanical oscillations. The transducer 6 is connected to a vessel 7 containing a cleaning liquid 19 for cleaning articles immersed therein.

The transistors 10, 11 are operated by a switching signal from controllable oscillator 13. A modulating arrangement 25 is connected to said switching transistors 10, 11 and said controllable oscillator 13, which arrangement is used for modulating said alternating current. A comparison device 26 is connected to said modulating arrangement and to a resistor 12 incorporated in the alternating current circuit, which comparison device provides an output signal varying with the sign of the modulated signal and being applied as a control signal to the controllable oscillator 13. In the embodiment shown the modulating arrangement 25 is formed by a signal generator 15 and a modulator 14 wherein the output signal from the controllable oscillator 13 is modulated by the output signal from said signal generator 15. The modulation signal provided by said signal generator 15 has a frequency which is considerably lower than the frequency of the output signal from the controllable oscillator 13. When the frequency of this output signal is, for example, 20 kHz, it is possible to choose, for example, 50 Hz for the frequency of the modulation signal. The output signal from the signal generator is also applied as a reference signal to the comparison device 26. In the embodiment described this comparison device is formed by a phase sensitive detector 18 one of the input circuits of which is connected through an amplifier 17 and a lowpass filter 16 to the junction between resistor 12 and direct current source 1. The modulation signal selected with the aid of lowpass filter 16 is compared in this phase detector, after amplification in the amplifier 17, with the modulation signal derived from the signal generator 15, the phase detector providing an output signal varying with the sign of the modulated signal and being applied as a control signal to the controllable oscillator 13.

For further explanation reference is made to the curve shown in Figure 3 which shows the variation of the operating current I_b as a function of the frequency. When the power on the primary side of the transformer 3 is measured, this power may be represented by $P = U_b.I_b$ wherein U_b is constant and equal to the voltage of the direct current source and I_b is the mean value of the direct current in the primary winding 4. As the output signal from the controllable oscillator is modulated in the modulator 14, the operating current will have an AC component whose amplitude and phase are dependent on the point on the curve I (f) as determined by the frequency. When the arrangement operates on the point of the curve which corresponds to the frequency f_o, the differen-

tial coefficient of the current I obtained after differentiation will be equal to 0 and no AC component is obtained. The current has its maximum value on this point and hence the maximum power is provided at this frequency.

When the arrangement operates on the point corresponding to the frequency f_1 as a result of a variation in the level of the liquid, the modulation by means of the modulation signal $\pm f_m$ results in an alternating current i_1 being obtained. This alternating current has a phase which is lagging with respect to the phase of the modulation signal. On the other hand, when the frequency has the value f_2, the modulation by means of the modulation $\pm f_m$ will produce an alternating current i_2 whose phase is leading with respect to the phase of the modulation signal. The currents i_1 and i_2 have the same frequency as the modulation signal f_m. The alternating current signal thus occurring, for example, i_1 or i_2 is selected by means of lowpass filter 16, subsequently amplifier in amplifier 17 and then applied to the phase detector 18. The modulation signal of the frequency f_m provided by the signal generator 15 is also applied as a reference signal to this phase detector. Dependent on whether the phase of the selected signal is lagging or leading with respect to the phase of the reference signal, the phase detector provides a positive or a negative output voltage which is applied to the controllable oscillator 13 so that the frequency of the output signal from this oscillator is increased or decreased until phase coincidence has been obtained. When phase coincidence occurs, the output voltage of the phase detector is equal to zero. The operating current I_b then has assumed its maximum value. The control loop described constitutes a negative feedback system which is adapted to adjust the frequency to a value at which the current is at a maximum. This value may be dependent on the load of the transducer producing the mechanical oscillations. Thus, the system has no absolute reference which is particularly advantageous since the magnitude of the maximum value of the operating current is not known in advance. The control loop thus tends to adjust the oscillator tuning in a manner such that it provides the maximum power adapted to the load.

WHAT WE CLAIM IS:—

1. An ultrasonic generator comprising a direct current source and two switching devices actuated by a controllable oscillator to provide an alternating current, a resonant circuit powered by said alternating current and control means for varying the frequency of said oscillator to optimize the energy transfer of a transducer, in which the control means comprises a resistor in the alternating current circuit, means interposed between the output of said oscillator and said switching devices for modulating the output signal of the oscillator at a lower frequency than the oscillator frequency to produce across said resistor a modulated signal with a signal component at said lower frequency, comparison means coupled to said resistor for deriving an output voltage whose polarity is determined by the phase relationship of said signal component relative to the lower frequency modulating signal and means for applying said output signal as a frequency control signal to said controllable oscillator.

2. A generator as claimed in Claim 1, wherein the said modulating means comprises a signal generator and a frequency modulator in which the oscillator output signal is frequency modulated by the output signal from the signal generator.

3. A generator as claimed in Claim 1 or 2, wherein said comparison means comprises a phase sensitive detector one input circuit of which connected to the alternating current circuit includes a lowpass filter for selecting the modulation signal, and the other input circuit of which is connected to the signal generator while the output of said phase sensitive detector is connected to said controllable oscillator.

4. An ultrasonic generator, substantially as herein described with reference to Figures 2 and 3 of the accompanying drawings.

5. Cleaning apparatus comprising an ultrasonic generator as claimed in any one of Claims 1 to 4.

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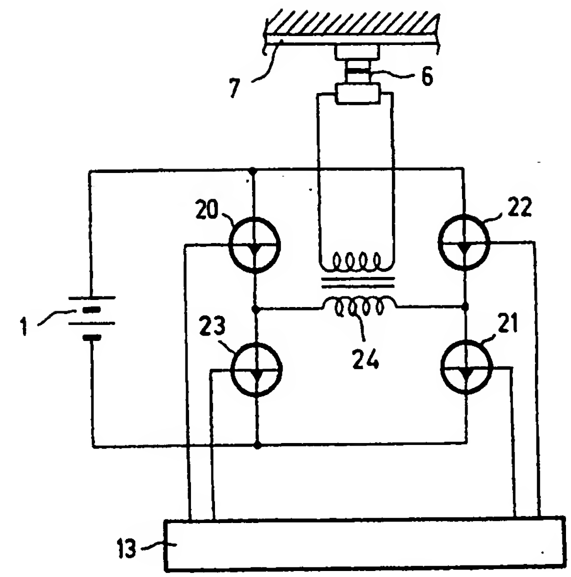

Fig.1

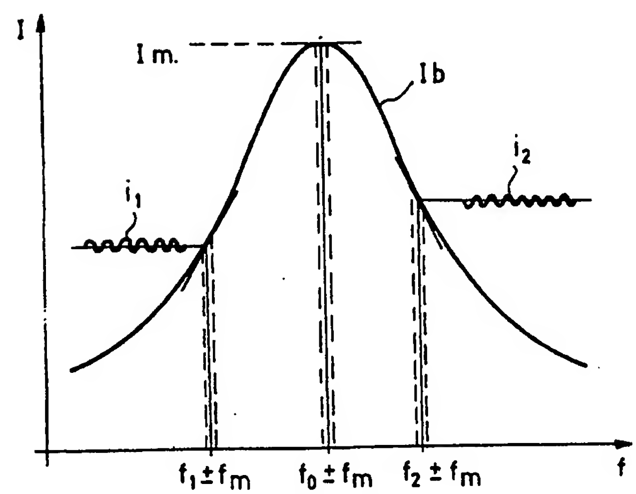

Fig.3

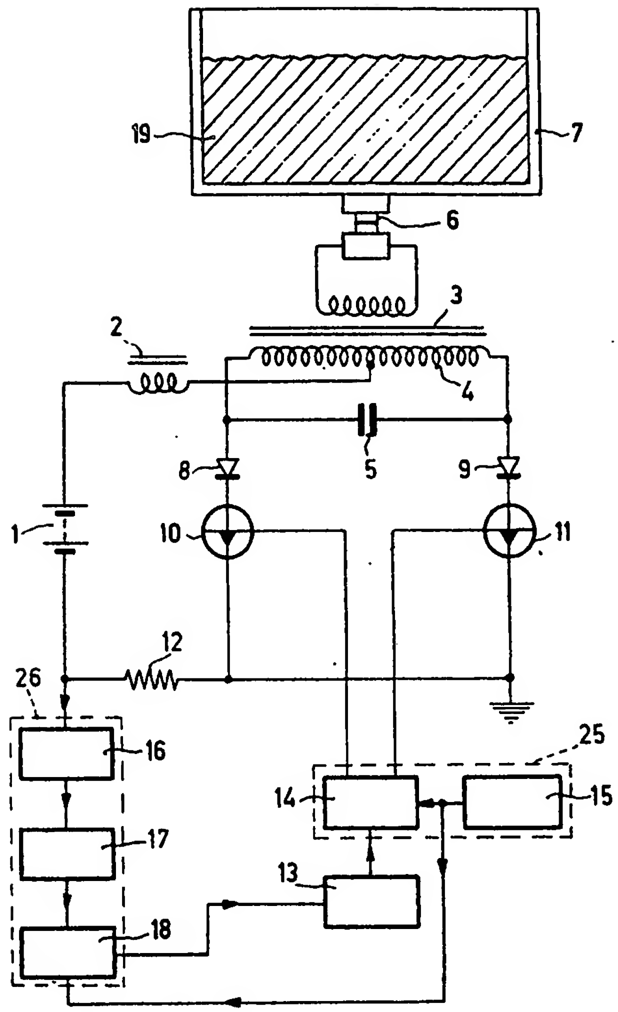

Fig. 2